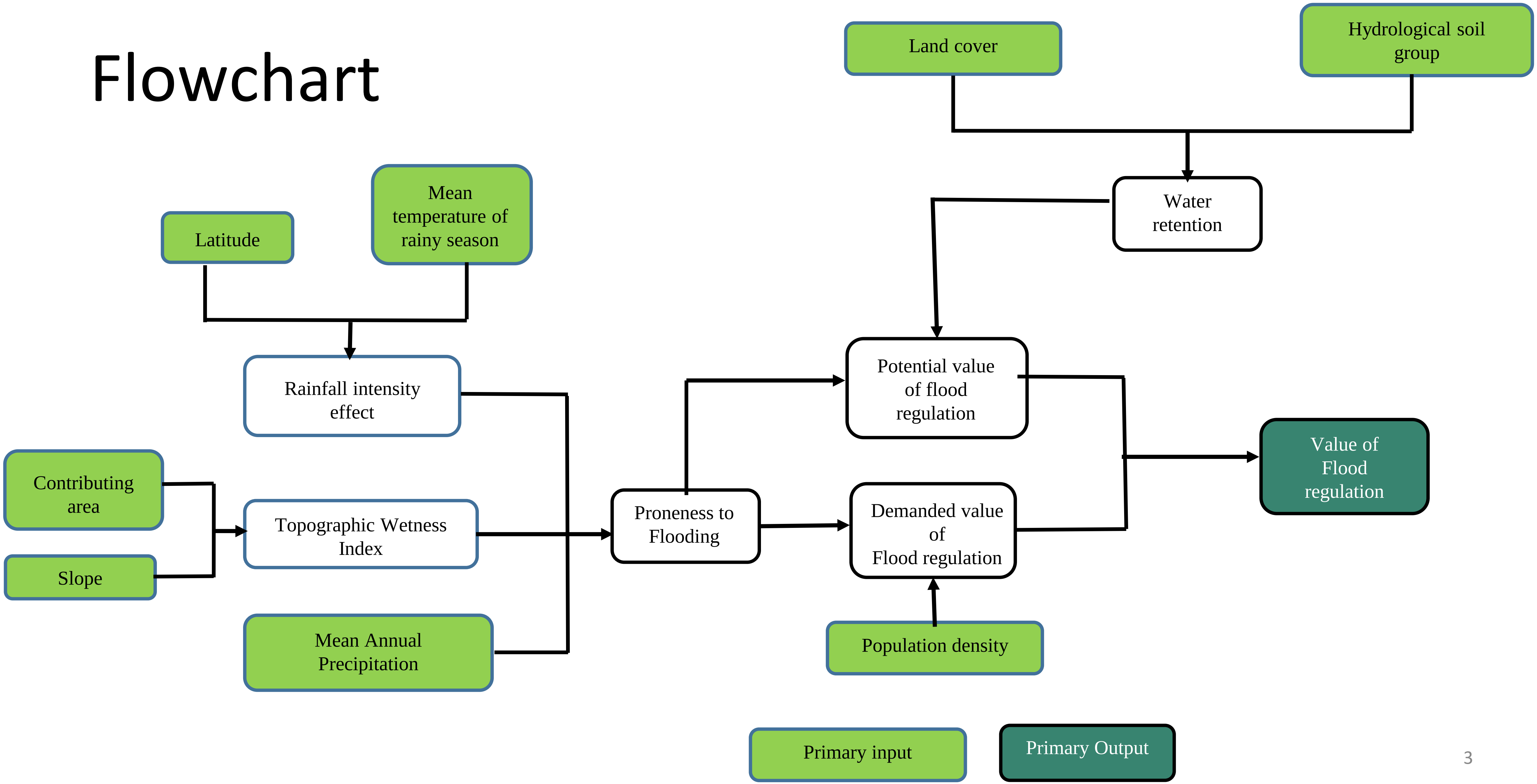
Flood regulation model

Overview

- This model quantifies ranked values for flood regulation supply and demand, accounting for:
  - Proneness to flooding (topography + precipitation)
  - Avoided runoff retained by soils and vegetation
  - Population density
- The model thus constitutes a simplification of previously published global or continental-scale ones (Stürck et al., 2014; Ward et al., 2015), but is fast and easily replicable even in data-scarce contexts.
- We describe a preliminary version that will be updated before the official ARIES release.

Flowchart

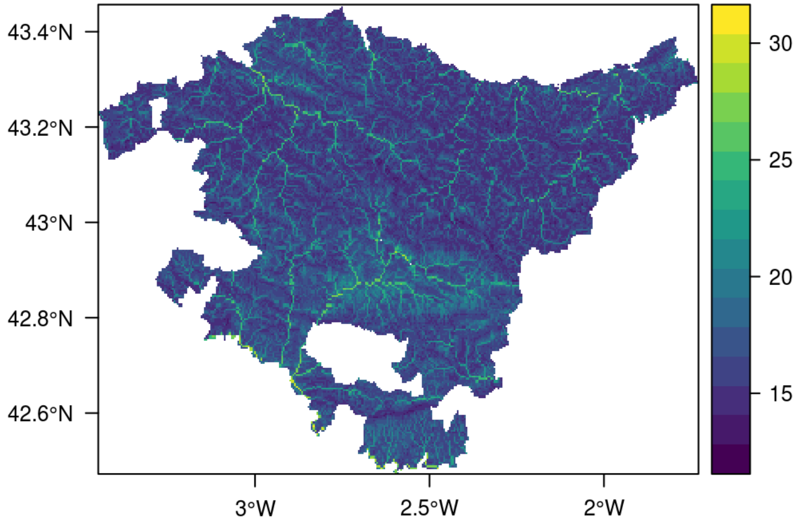

Land cover
Hydrological soil group
Water retention
Latitude
Mean temperature of rainy season
Rainfall intensity effect
Contributing area
Slope
Topographic Wetness Index
Mean Annual Precipitation
Proneness to Flooding
Potential value of flood regulation
Demanded value of Flood regulation
Population density
Value of Flood regulation
Primary input
Primary Output

1. Probability of runoff to cause flooding

- Estimated as average of:
  - Topographic wetness index (TWI), a steady-state wetness index based on:
    - Slope
    - Contributing area (Kirkby and Beven, 1979; Manfreda et al., 2011)
  - Mean annual precipitation
  - Mean temperature of the wettest quarter (Hijmans et al., 2005).

Topographic Wetness Index

```
model occurrence of earth:Region with im:Still earth:PrecipitationVolume
    observing
        geography:Slope in degree_angle named slope,
        hydrology:ContributingArea in m^2 named contributing_area
    set to [
        def sloperadians = Math.tan((slope * 1.570796 ) / 90)
        def twi = Math.log( (contributing_area+1) / Math.tan( (sloperadians+0.001) ) );
        return twi;
    ];
```

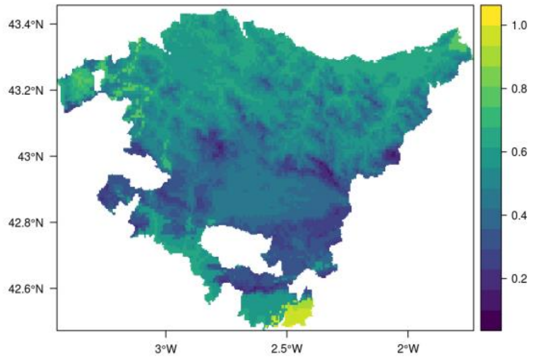


Rainfall intensity effect

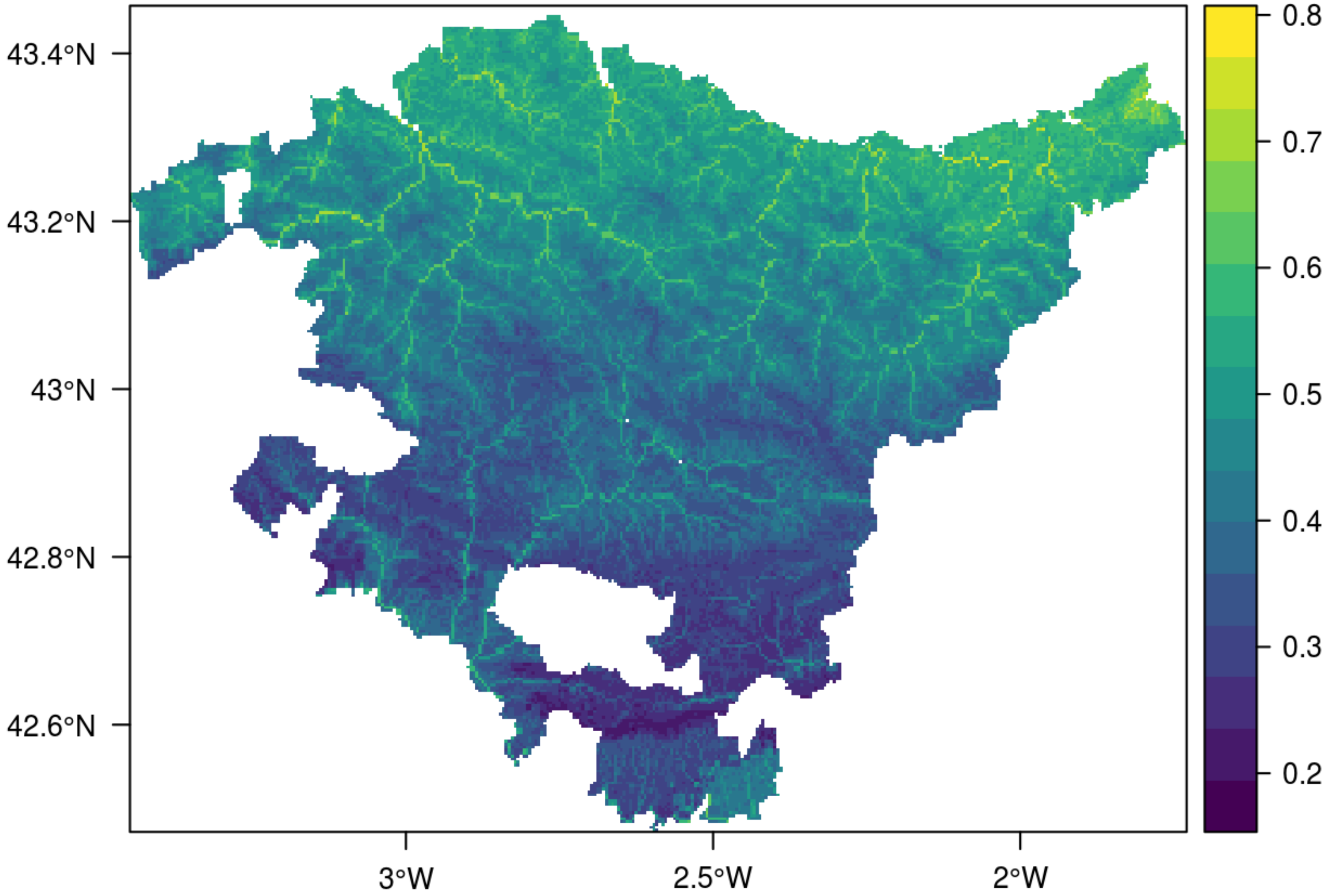
- Temperature is included in the equation to account for the role of the Clausius-Clapeyron relationship (Trenberth et al., 2003), which predicts greater rainfall intensity at higher temperatures
- Based on Utsumi et al. (2011), the model uses mean atmospheric temperature in the wettest quarter to predict:
  - An increase in the temperature-rainfall intensity relationship in polar regions (high latitudes)
  - A decreasing relationship in equatorial regions (tropics)
  - A peaked relationship in temperate regions (intermediate latitudes)

Rainfall intensity effect

```
model proportion of earth:PrecipitationVolume caused by earth:AtmosphericTemperature
    "Temperature effect on rainfall intensity"
    observing
        earth:LatitudinalRegion named latitudinal_region,
        im:Mean earth:AtmosphericTemperature during (earth:Wet earth:Season) in Celsius
            named mean_wet_season_temperature,
        im:Normalized (im:Mean earth:AtmosphericTemperature during (earth:Wet earth:Season)) in Celsius
            named normalized_wet_season_temperature
    lookup (latitudinal_region, mean_wet_season_temperature) into
            region          |   mean_temperature  |       result
        ----------------------------------------------------------------
        earth:Polar         |         *           | [normalized_wet_season_temperature],
        earth:Tropical      |         *           | [1 - normalized_wet_season_temperature],
        earth:Temperate     |       < 22          | [normalized_wet_season_temperature],
        earth:Temperate     |       > 22          | [1 - normalized_wet_season_temperature];
```



Flood proneness (computed using topographic wetness index, annual precipitation, temperature effect on rainfall)



2. Avoided runoff caused by vegetation

- The model computes potential flood regulation using the Curve Number (CN) method, which estimates the capacity of vegetation and soils to retain excess runoff from rainfall
- CN (0 - 100) is a function of:
  - Land cover
  - Hydrologic soil group data
  - Slope (in some contexts)

(Zeng et al., 2017; Soil Conservation Service, 1985)

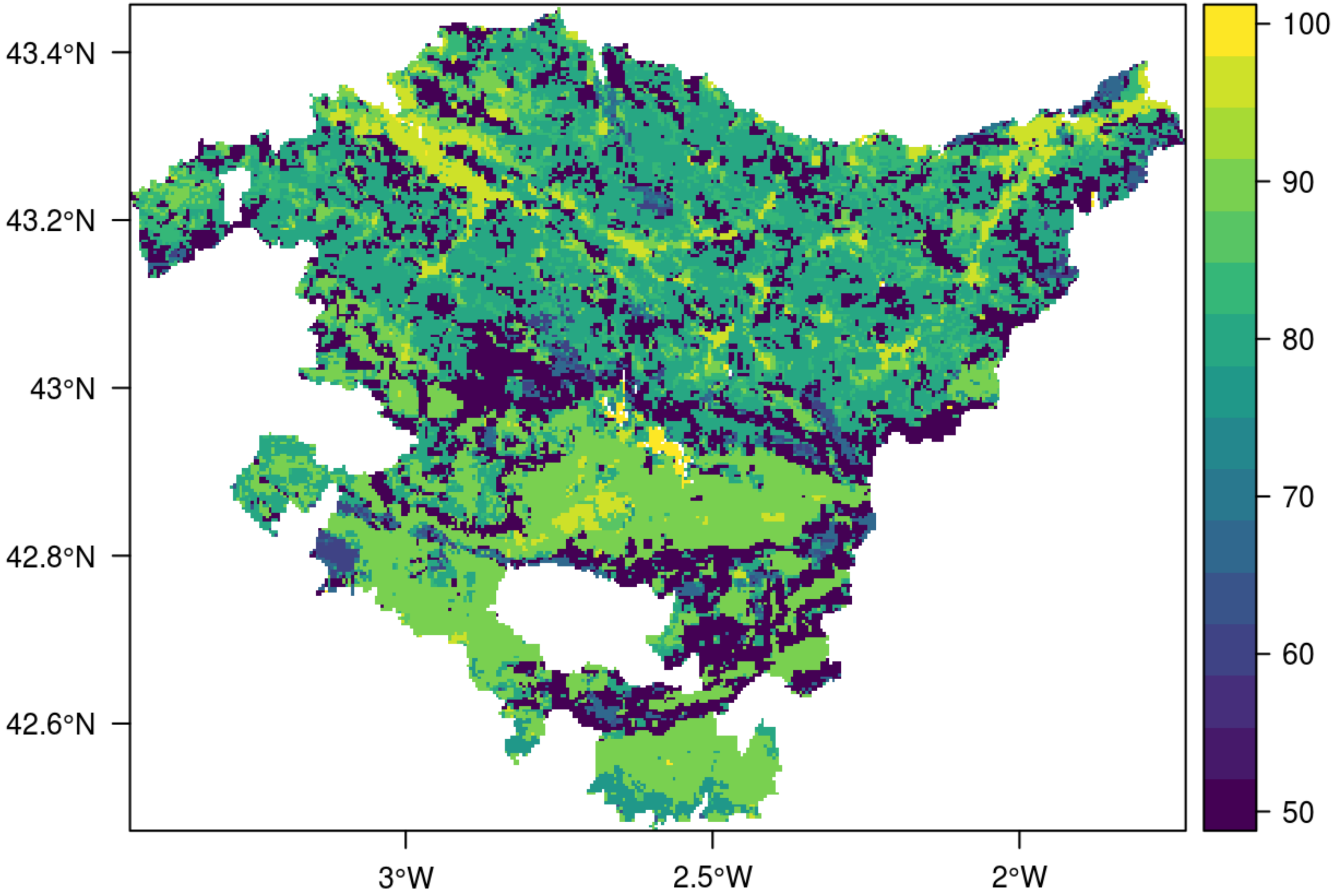
Curve numbers come from lookup tables

Customizable for different regions and for comparison with “unvegetated” context

```
define CURVE_NUMBER_TABLE as {{

      landcover                                | hydrological_soils_group | curve_number
   ------------------------------------------------------------------------------------
   landcover:ArableLand                        |   hydrology:SoilGroupA   |   67     ,
   landcover:ArableLand                        |   hydrology:SoilGroupB   |   78     ,
   landcover:ArableLand                        |   hydrology:SoilGroupC   |   85     ,
   landcover:ArableLand                        |   hydrology:SoilGroupD   |   89     ,
   landcover:PermanentCropland                 |   hydrology:SoilGroupA   |   67     ,
   landcover:PermanentCropland                 |   hydrology:SoilGroupB   |   78     ,
   landcover:PermanentCropland                 |   hydrology:SoilGroupC   |   85     ,
   landcover:PermanentCropland                 |   hydrology:SoilGroupD   |   89     ,
   landcover:HeterogeneousAgriculturalLand     |   hydrology:SoilGroupA   |   52     ,
   landcover:HeterogeneousAgriculturalLand     |   hydrology:SoilGroupB   |   69     ,
   landcover:HeterogeneousAgriculturalLand     |   hydrology:SoilGroupC   |   79     ,
   landcover:HeterogeneousAgriculturalLand     |   hydrology:SoilGroupD   |   84     ,
   landcover:EvergreenBroadleafForest          |   hydrology:SoilGroupA   |   30     ,
   landcover:EvergreenBroadleafForest          |   hydrology:SoilGroupB   |   58     ,
   landcover:EvergreenBroadleafForest          |   hydrology:SoilGroupC   |   71     ,
   landcover:EvergreenBroadleafForest          |   hydrology:SoilGroupD   |   77     ,
   landcover:DeciduousBroadleafForest          |   hydrology:SoilGroupA   |   42     ,
```

Curve number



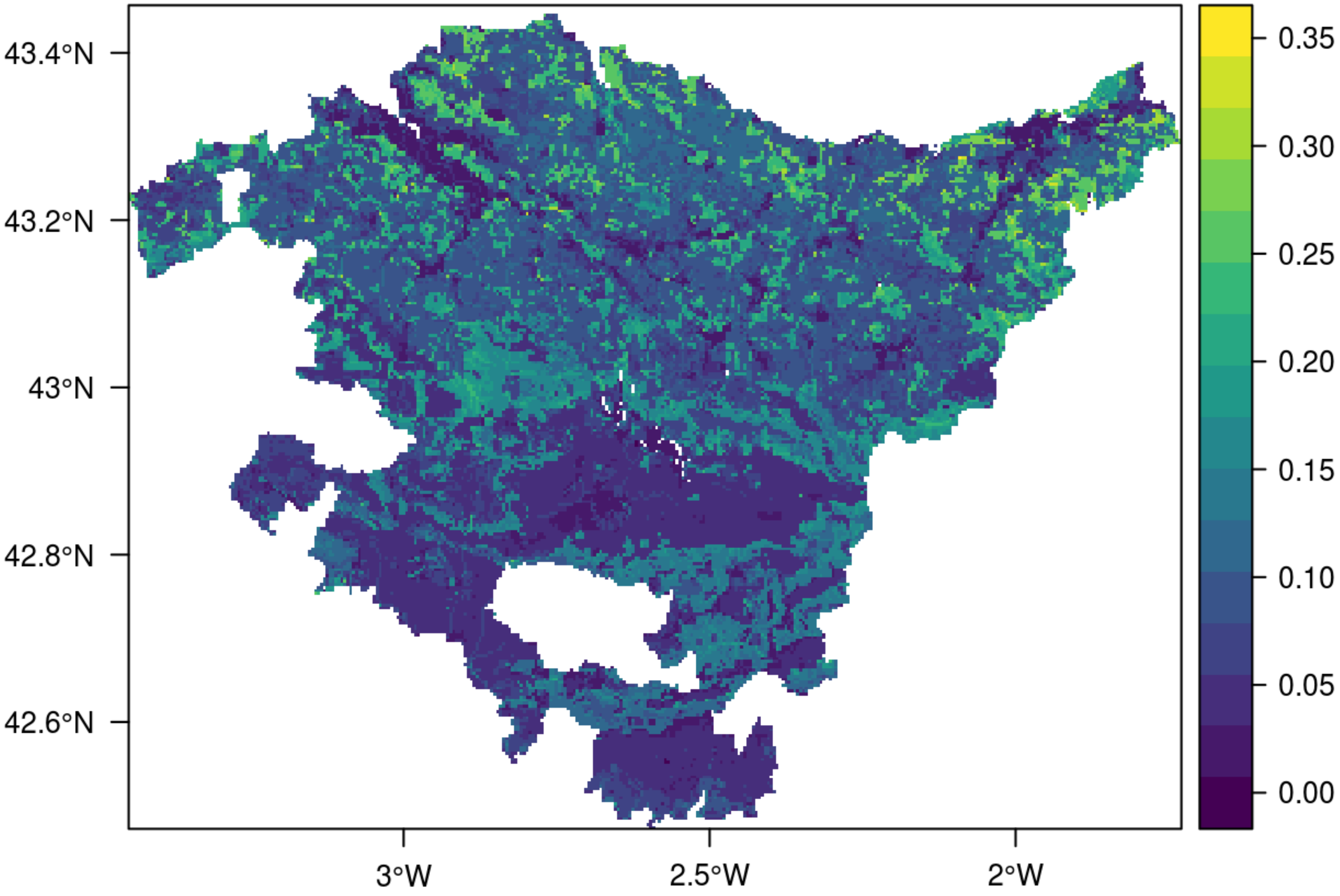
Potential flood regulation

The model then compounds the probability of water pooling with the runoff avoided by vegetation:

Probability of Standing water * avoided runoff

```
model im:Potential value of es:FloodRegulation
    observing
        im:Differential hydrology:RunoffWaterVolume caused by ecology:Vegetation in mm named avoided_runoff,
        im:Potential proportion of earth:PrecipitationVolume causing earth:Flood named proneness_to_flooding
    set to [avoided_runoff * proneness_to_flooding];
```

Potential flood regulation

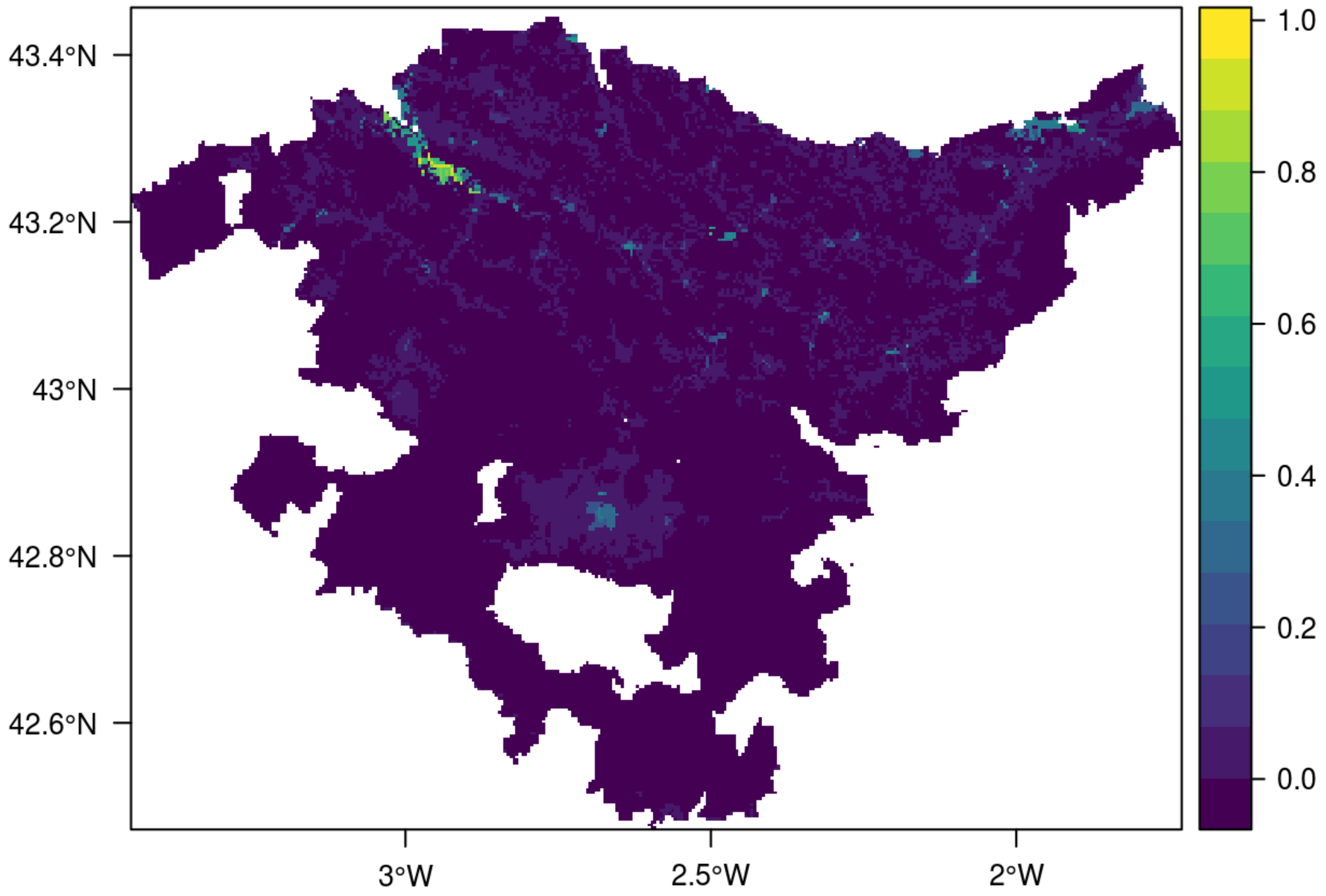


Flood Regulation demand

- The model estimates flood regulation demand by multiplying (Proneness to Flooding) by (population density), providing a ranking of the relative exposure of people and property to flood risk.

```
model ses:Demanded value of es:FloodRegulation
    observing
        probability of earth:Flood named flood_probability,
        count of demography:HumanIndividual per km^2 named population_density
    set to [flood_probability * population_density];
```

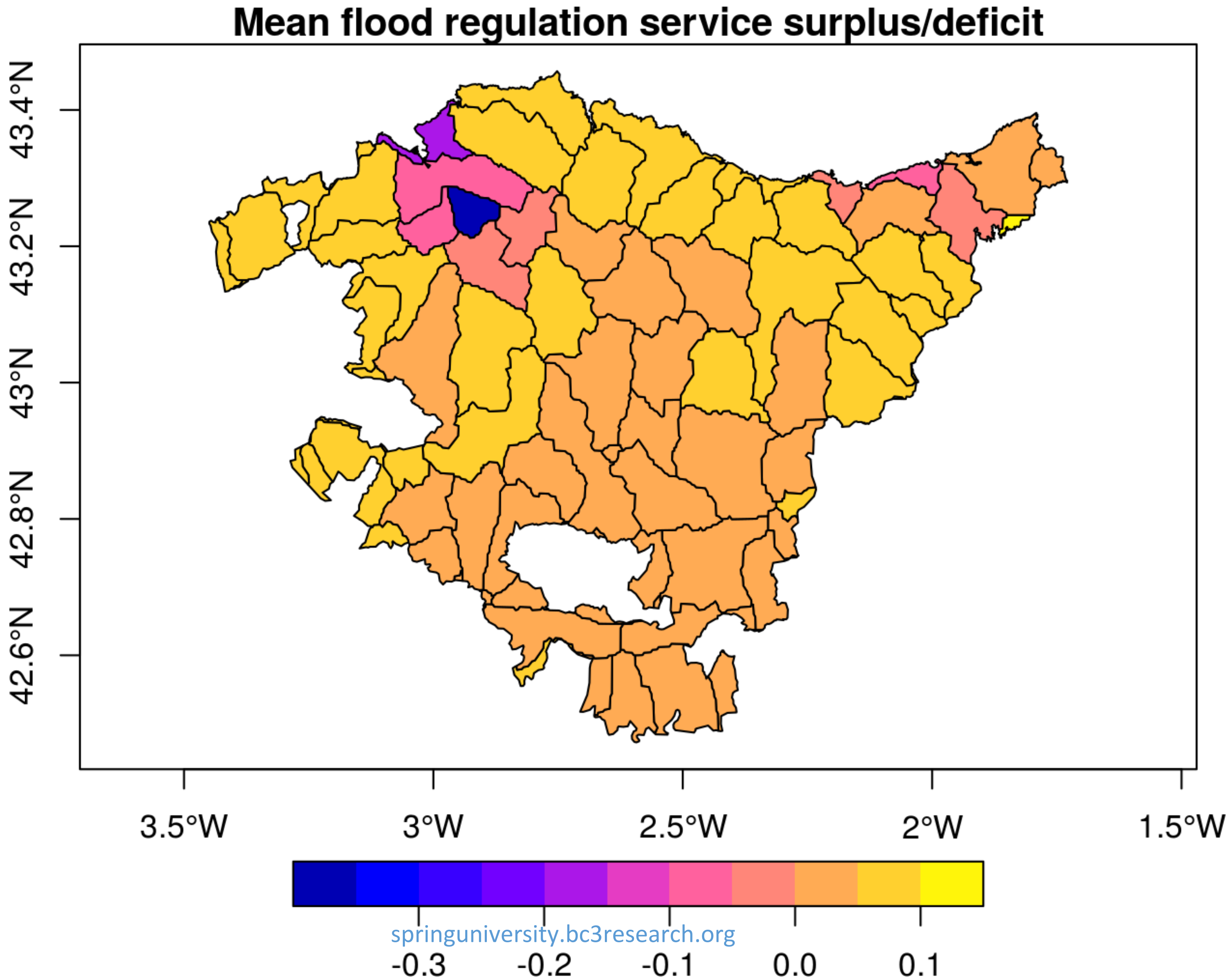
Flood Regulation demand



Total value of Flood Regulation

- Finally, the model preliminarily estimates the value of Flood Regulation as supply times demand.
- The model is a prototype due for revision by the release date.
- More realistically, value will be automatically:
    - computed on a watershed basis, with automatic delineation of watersheds in the context;
    - Computed using each individual storm event, based on weather station data, and aggregate the risk of flooding per event to obtain the likely distribution of damaging events during the period of interest.

Aggregation by watershed



Examples of model customization

- Local data for land cover, slope, soils, climate, etc.
- Local curve number lookup tables:
  - Basque Country (Ferrer-Julia 2003)
  - U.S. Southwest (Tillman 2015)
  - East Africa (Bagstad et al. 2018, adapted from Baker and Miller 2013)